A Head-up Display with Augmented Reality and Gamification for an E-Maintenance System: Using Interfaces and Gamification to Motivate Workers in Procedural Tasks

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Abstract. A current challenge in industrial systems, such as E-maintenance, responsible for gathering all maintenance-related data in a single system, is how to display information to users. This same challenge is present when considering new devices for visualization, such as Head Mounted Displays -HDM (e.g. Google Glass). Advanced interfaces such as Augmented Reality (AR) and Head-Up Display (HUD) provide a means to display these information for users. However, there is still a lack of theoretical design studies (studies that do not consider current technologies limitations) of Augmented Reality and HUD. Another problem in industrial scenarios is motivation, especially considering repetitive procedural works. Therefore, this paper present and discuss a high fidelity theoretical prototype of an interface for maintenance, that uses Gamification techniques to motivate the user, and AR and HUD to display information in a HMD device.

Keywords: Augmented reality · HUD · Gamification · Maintenance

1 Introduction

A current challenge in the maintenance of industries is obtaining and using knowledge. E-Maintenance is a new field of Information and Communication Technology that unites maintenance engineering with software engineering, management and business administration [1]. It is defined as the union of two tendencies in industry [1]: the rising importance of maintenance and the accelerated development of Information and Communication Technologies.

Information in an E-Maintenance system must be used to extract rules to generate knowledge, which will be capitalized to create a corporative memory of the company. Nevertheless, visualization solutions for such knowledge are scarce, as studies show that 45 % of an operator shift is spend searching and reading procedures [2].

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Bagemann et al. [3] reinforces the need for visualization solutions in project PROTEUS, by defining the delivery of data to operator actors in a strategic and tactical level as one of the three central functions.

Another E-maintence system, TELMA, also discusses the importance of using PDAs or Head Mounted Displays (HMD) for visualization, increasing the user understanding of the situation [4].

Consequently, several studies were conducted about industrial accidents, and the incorrect manipulation of the process by the operator was appointed as their major cause [5]. They prove that data visualization in maintenance, both in procedure and intelligence level, are crucial. In contrast, considering mobile user interface design (both PDAs and HMDs are mobile), Sá and Carriço demonstrated that studies of design or with a user centered perspective are lacking [6].

Augmented Reality (AR) is a potential technology for data visualization in E-Maintenance, because it can bring knowledge to the physical world, assisting operators to execute their tasks without stopping to consult manuals. There are already many solutions that use AR in maintenance, and some of them are analyzed in Oliveira et al. [7].

Furthermore, considering HMDs, another visualization technology to explore is a Head-Up Display (HUD), in which the User Interface (UI) is projected in the display. In this paper, the word HUD is used based on the Game Development domain, in which it is considered a way to present information to users, in other words, a user interface media (and not a device). Therefore a HUD interface refers to 2D information projected on the user display.

Combining both solutions, an interface with HUD and AR elements should:

- Display as little information as possible, while providing the necessary information in the correct time;
- Allow easy access to data and optimize the information presentation;

Besides visualization, another need in industries is motivation solutions. There is a direct influence between skill and motivation, because, although high skill indicates possible high productivity, motivation is the lever that controls the final result of efficiency. As studied by Kiassat [8], motivation and boredom are two of the main factor responsible for error in some industries.

A motivation strategy currently discussed in work environments is Gamification, in which game design techniques are applied to work problems [9]. Even in procedural tasks, classic game design motivation techniques can be applied to motivate users [10].

In this paper it is proposed and analyzed a high fidelity User Interface prototype for maintenance activities, which uses AR and HUD as visualization technologies, and Gamification as a motivational technique for the procedural tasks. This theoretical interface and the application underneath it are connected to an E-Maintenance System, to be able to obtain, in real time, data for the user. The focus of the paper is not on technological constraints and therefore any current limitation is ignored to provide an optimal User Interface.

This paper is divided in: (II) reward and motivation theory; (III) the procedure; (IV) the User Interface prototype; (V) discussion and conclusions.

2 Reward and Motivation

Umstot et al. [11] were among the firsts to suggest strategies to enrich the work and make it more interesting, challenging and significant. This could be done by adding dimensions such as abilities variety, task identity, task significance, autonomy and feedback. These factors, together with communication with other people, are essential to ensure motivation and satisfaction.

Procedural tasks can lack these dimensions. Therefore, workers that face routines that are too specialized or simplified, besides feeling unsatisfied with their activities, can also face negative physiological consequences, such as RSI (Repetitive Strain Injury). Examples are works in assembly lines, or those in which a machine forces the rhythm the worker has to follow.

Maintenance, which is the domain explored in this paper, is a strictly procedural work, although with some unpredictability. Beyond being repetitive, it usually leaves a low margin for high level and impactful decision making, reducing the satisfaction levels in this type of work.

Procedural tasks are also common in many games, one category being MMORPG (Massive Multiplayer Online RPG), due to the necessary repetition of actions to obtain better rewards (also called grinding in game development). The main difference of what generally makes an MMORPG "fun" and a procedural industrial task "boring", is the immediate reward and the expectancy of getting better rewards.

The Skinner Box theory [12] explains why conditioning players in MMORPGs is possible. This theory proves that it is possible to project a behavioral modification system based on the systematic reinforcement of the desired behavior, in other terms, give an immediate reward for a task. Therefore, by stimulating and satisfying their users with instant rewards, MMORPGs become engaging, while maintenance can be considered boring.

This theory is taken to extreme levels by some game developing companies, making games that are borderline gambling, causing compulsive addiction in users. Many studies were made to understand the nature of addiction in online gaming [13] or to identify if these games are passing the barrier of illegality [14].

One of the methods used currently to improve user satisfaction with work is Gamification, which is applying game elements and game design techniques to non-game related problems, such as business and social challenges. Gamification is applied to improve user experience and engagement in a task [15], usually through a simple reward system (therefore, it's a Skinner Box). As far the authors know, there are no applications of Gamification as a motivating force in maintenance.

Several Gamification strategies can be used to improve motivation/satisfaction and decrease boredom. For example, in the simpler level, interfaces could be graphically designed to look like games, just to give users the idea of being in a game. In a medium level, interfaces can be used to display the user reward (salary) for executing a task, both in regular salary (man-hour value) and in the annual bonus calculated based on performance. Finally, in a more advanced level, Gamification could be applied to dictate each user task, for instance, placing the work inside a real game.

The focus of this paper is on the medium level of Gamification, whereas the financial reward of the user for his task will be integrated in real time with the UI. Furthermore, key performance indicators established by companies will be used to increase even further the feeling of immediate reward. These indicators are indices used by enterprises to define and measure an employee performance, and usually an annual bonus is calculated based on these indicators.

In this paper, the four key performance indicators used are: assiduity, safety, mission and record. Assiduity is assessed by punctuality and absenteeism. Safety is evaluated by fulfilling norms and policies. Missions are evaluated by completing tasks, considering that each task demands a different level of effort and therefore they have different weight in the score. Finally, record is assessed by comparing the user performance with the mean performance of all collaborators, in other words, comparing how above the mean was the user for a task.

3 The Procedure

The task example showed in this paper uses dummy data and the step by step process and the values presented are merely illustrative:

- User arrives at work and logs in the system;
- Receive the task and accept it;
- Request information about the equipment, including reliability and sensor information;
- Equips the Personal Protective Equipment (PPE);
- Executes a preventive test in the airplane turbine;
- Opens the turbine and identifies a problem;
- Fix and replace a specific asset;
- Receives a score for the task.

4 The UI Prototype

E-maintenance technology has the goal to facilitate access to any maintenance-related data to users. However, few studies show how a User Interface for such a system would be. Therefore, in this section, a UI prototype is presented, with the goal to display data already available in E-Maintenance systems, but currently inaccessible in tasks of a technical nature.

The first set of UIs is an introduction to the system, routine and tasks, and can be seen in Fig. 1. Interface A is the first one showed to the user (after he logs in the system), and gives as options access to tasks, a calendar with the planning of the day, reports and news. The first step to Gamification is in there, because the user can also access a personal and team ranking. This ranking is created based on the result of each mission (showed to the user at the end of the task). The goal is to motivate users, allowing them to compare their performance in real time with their coworkers.

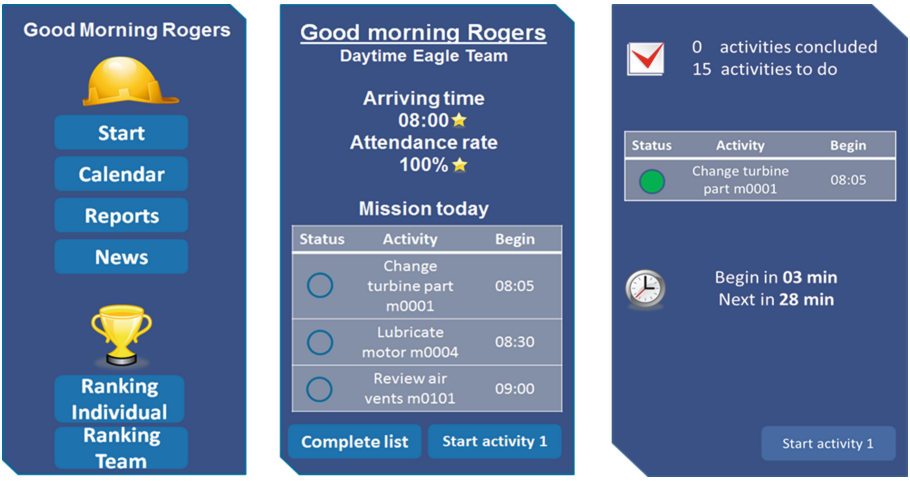

Fig. 1. (A) Initial system UI; (B) Daily routine UI; (C) Task initiation UI

Interface B of Fig. 1 is designed to introduce users in theirs daily schedule. This interface also introduces the first key performance indicator, assiduity, by ranking the user based on his/her punctuality and absenteeism.

Interface C is the start of a new task, showing the necessary procedures and the estimated time to complete each procedure.

The second interface, from Fig. 2, has the goal of presenting equipment detail to the user. In this figure, interface A shows the equipment and some related information. Interface B displays statistical data about the equipment, such as reliability (calculated

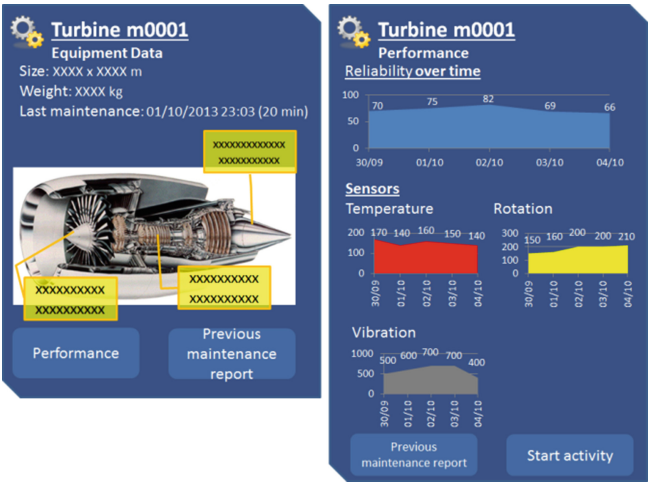

Fig. 2. User Interface for complex data and information about an equipment

over the lifetime of the equipment), and sensor data collected over the last operation (vibration, temperature, rotation).

Interface of Fig. 3 is a combination between Augmented Reality and HUD. In the upper left corner, there is a list of equipment the user should acquire, with markings to show which ones were already obtained. Additionally, a green light is projected on top of the next equipment to be acquired (in this case, the glasses), to guide users in choosing only the necessary and correct equipment. Furthermore, in the right corner of the screen, there are buttons representing additional features of the system. They allow users to film or take pictures in real time of the work, to start a VOIP conversation when in need of help, to access system documentation and help and to visualize a map of the place.

Interface from Fig. 4 is activated when a preventive test is executed in the equipment. During this test, a HUD element is showed with real time information, in the form of graphics, of the equipment sensors. Complementing the HUD, there are three information projected on top of the equipment, based on the sensors reading. Temperature is projected in the turbine through a colored heat map. Rotation is projected through a circular green arrow, to demonstrate rpm. Finally vibration is projected through the yellow arrows located around the turbine, and they move according to the current vibration.

Figure 5 shows an interface to warn users about possible risks identified in the equipment, by projecting messages on top of the parts that are the source of the risk. In this figure, UI was visually expanded to improve readability. Risks are also classified in category and danger level, and to avoid clutter it is possible to filter only by category or danger.

Fig. 3. Track assistant interface to help equip protective personal equipment

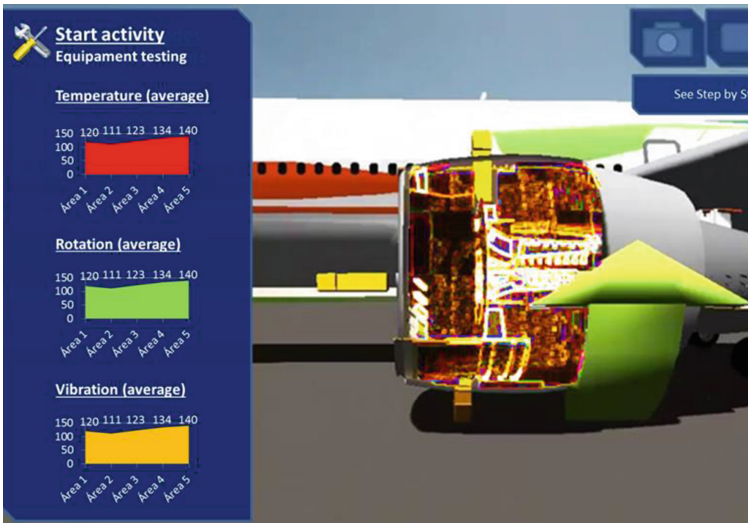

Fig. 4. Interface using AR by projecting sensor measured data (temperature, rotation and vibration) on top of the equipment.

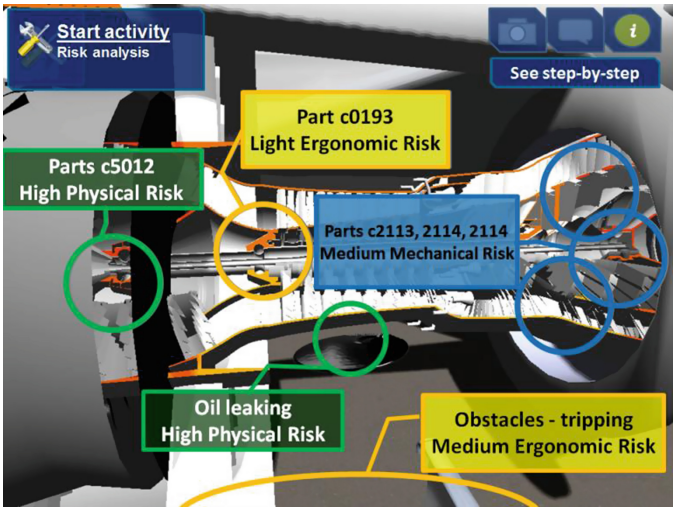

Fig. 5. Interface to improve risk awareness (information size in this figure is increased for better visualization in the paper).

Interface from Fig. 6 guides users through a procedure. In this UI, there is a HUD showing the amount of steps from this procedure, and the current one. There is also an AR interface showing what and where is the current step, highlighted and blue, and the next two steps, uncolored. A more produced AR assembly interface can be seen in Henderson and Feiner [16].

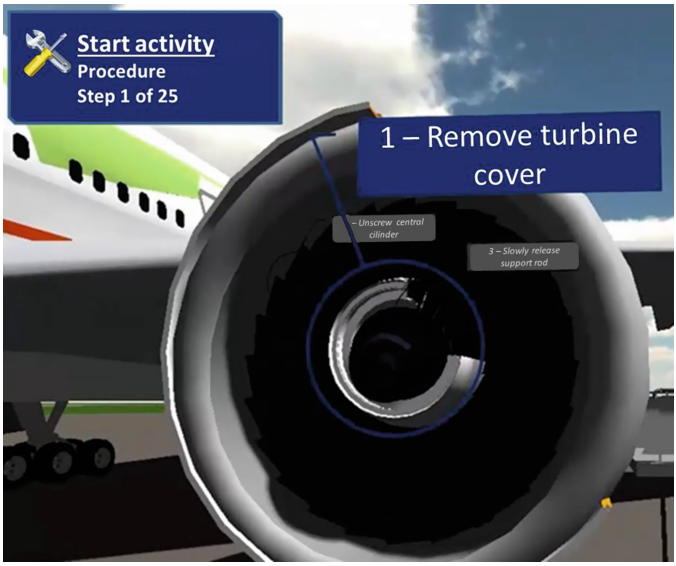

Fig. 6. Procedure guidance interface

In Fig. 7 there is an interface showing the result of the user task performance. Presented in interface A is the time spent on the procedure, and then the score received in assiduity, safety ("following policies and procedures"), mission ("change of turbine part") and record, although in this last the user didn't received any score. In interface B the user score is compared with other coworkers. Both interfaces have the goal to motivate our user by showing information about performance to give an immediate feedback, and the colleagues' performance to promote a healthy competitiveness in the work.

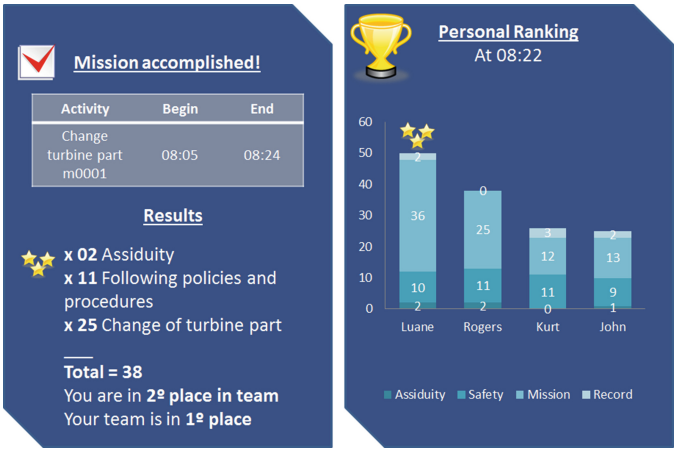

Fig. 7. User Interface with performance feedback based on key performance indicator

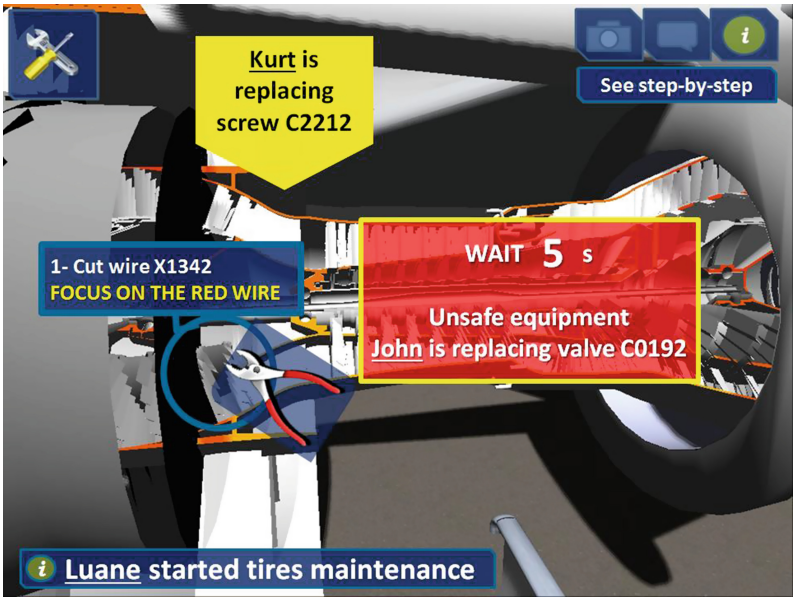

Fig. 8. Interface for teamwork awareness

Finally, interface from Fig. 8 was added to the paper, even though it is not part of the procedure, to illustrate a UI of teamwork awareness. In this interface, the WAIT sign was designed to capture the user attention and help in synchronizing steps of the user procedure with dependencies with other coworkers' procedures.

At the same time, the interface is also informing what two other coworkers are currently doing. Whenever a coworker is near the user, the interface displays their activities in the form of AR (projected on top of them), such as the warning "Kurt is replacing screw C2212". On the other hand, when the coworker is far, their activities are displayed as a HUD in the corner, such as "Luane started tires maintenance".

Finally, the user activity is displayed on top of where it should happen, with a picture of the necessary tool, description of the action and a warning of common mistakes ("Cut wire X1242. Focus on the red wire.").

5 Discussion and Conclusions

This paper proposes a high fidelity UI prototype for maintenance activities, which uses Augmented Reality and HUD in a Head Mounted Display as visualization technologies, and Gamification as a solution to the motivation problem in procedural tasks.

The proposed User Interface prototype has several goals. The first goal is to demonstrate how Gamification can be used in a maintenance context, both in input data and presentation output.

Gamification is applied to improve user experience and engagement in a task [9,10], normally through the theory of operant conditioning chamber (also known as the Skinner box) [12], which proves that it is possible to design a system of behavior modification based in the systematic reinforcement of the desired behavior, in other words, to give an immediate reward for the accomplished task.

There are several ways to explore Gamification in a work context, and this prototype explored the user performance indicator, also known as Key Performance Indicator (KPI) [17]. These indicators are defined by each company, and in this paper the indicators assumed are assiduity, safety, mission and records. Based on these indicators, many decisions could be made in the enterprise, such as vertical or horizontal promotions or an annual bonus.

Another goal is to explore a HUD-like interface for access to complex data and information in maintenance, considering the E-Maintenance system. In Figs. 1 and 2, UI would be voice controlled, therefore the possible interactions have be clear for users.

The third goal is to propose different forms of AR in maintenance, considering technologies aggregated by the E-Maintenance system. An example of technology is the Internet of Things (IoT), which will deploy sensors in objects of the work place and allow a reading of the environment through them. Aware of this richness of information, Figs. 3, 4, 5, 6 and 8 were prototyped to use AR to display real time sensor data to users.

The next goal is to explore procedure and risk awareness of the maintenance activities in a UI. Several AR interfaces for maintenance were proposed in literature [7], but always focusing on procedure, while the prototype in this paper also focus on awareness of risks during the task (Fig. 5).

The last goal is to explore a team awareness interface. The improvement of team situation awareness is an important research in industry [18], especially to avoid accidents, and the prototype from Fig. 8 is a step in this direction.

Finishing this discussion, a future option is to integrate the interface (and the application) in a higher level of Gamification (the advanced level). This would imply the connection of the application to a virtual world, in such a way that real world actions would (like the correct and efficient execution of a task) give virtual rewards to the worker. For instance, a day of work could result in an item or virtual coin in a virtual game (like a facebook game, or an MMORPG like World of Warcraft). This way, users would feel real life connect to the virtual world, and could be motivated by not only physical (material) rewards like money, but also virtual rewards, and thus be motivated through this virtual gratifications. According to Reeves and Read [15], this practice is unavoidable and will probably be applied to every work in the future, as a way to stimulate and motivate to obtain higher productivities.

Besides Gamification, there are other strategies that can be used to motivate workers and can be adopted in the future. Big data could be used to collect interesting information about the person life that can help motivate, such as the following messages demonstrates (they are presented to the user):

- Remember that today your "*favorite sport team"* is playing at 10 pm, and in days that you conclude more than 5 missions, your team has a 75 % win rate. Keep up the good work!
- This is the last mission today and the guiding system will follow you closer to assist finishing it faster, so you can go home. By the way, your son just posted that he arrived home.
- This mission will be long, with an average duration of 8 h. However, by the end of it, you will have fulfilled your goal for the month!

Concluding, in this paper it is explored a User Interface without technological limitations for maintenance activities, considering visualization and interface solutions, such as Heads-up Displays (HUD) and Augmented Reality (AR), and design proposals for enhancing the user motivation, such as Gamification. In future projects, this prototype will be evaluated with usability heuristics and user testing in a simulated virtual environment.

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